Reliability Analysis of Moored Marine Structures
Final Report

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Project Overview:

This project has studied a number of asspects concerning the reliability analysis of various marine structures and vessels. Our objectives have included the following:

1. To develop methodology sufficiently flexible to capture both long- and short-term behavior, which may be conveniently calibrated from environmental data available to the marine structural analyst and designer.

2. To reduce the computational expense of nonlinear stochastic analysis, which may become prohibitive for large numbers of response variables, by identifying more efficient analysis techniques.

3. To perform parametric studies of simple marine structures, to test feasibility of various methods and assess relative significance of various sources of nonlinearity and uncertainty (as well as correlation effects, e.g., between random wave, wind, and current in the same and different seastates).

These studies will ensure that the most important stochastic and mechanical elements of the problem are identified and maintained. Such results will also help identify which oceanographic environmental statistics are most important to accurately assess marine structural reliability.

Methodology Developed:

During this work we have developed a promising variety of stochastic analysis techniques for nonlinear problems. For example, narrow-band wave models
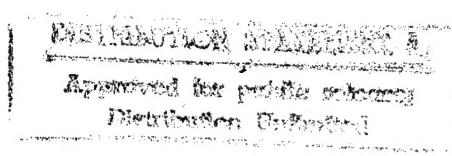
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have been used to estimate power spectra and higher moments of wave forces on offshore structures and ships. Corresponding spectra and higher moments of the resulting response of 1DOF-linear systems have been estimated by separable cumulant models. For Volterra series models from second-order diffraction analysis, response spectra and moments are given by eigenvalue analysis.

Specific Topics and Results:

Extreme Springing Motions of Moored Structures. For a stiffly tethered ocean structure such as a tension-leg platform, tether tensions and vertical platform motions show clear nonlinear effects due to second-order wave diffraction forces. These effects are most pronounced on acceleration responses, which amplify sum-frequency contributions. In addition, the power spectra of wave forces in heave and pitch are found to oscillate rather rapidly near typical heave and pitch natural frequencies. This implies that these frequencies and associated damping ratios should be selected with care, and that uncertainty in these quantities may have significant impact. Finally, as noted below, two critical seastates have been identified for extreme response: one governed by extreme wave height, and the other governed by wave period (specifically, with wave period twice that of the structure).

Nonlinear Random Waves and Extreme Crest Height. Most common non-linear wave models are deterministic; e.g., common Stokes waves, of various orders, which repeat periodically. Some limited models of nonlinear random Stokes waves have been proposed, but are often found more nonlinear than observed waves (i.e., too highly skewned). We have corrected this effect with new nonlinear random wave models, either through (a) an empirical skewness reduction factor based on observation, or (b) a new narrow-band nonlinear model, whose negative low-frequency term reflects wave set-down in shallow water. These models were found to accurately predict North Sea wave statistics. With the narrow-band model described above (see Metholodogy), extreme wave crests are conveniently estimated for probabilistic design of ocean structures.

Dynamics of Flexible MDOF Ocean Structures under Nonlinear Forces. We have previously developed a simple nonlinear response analysis method for

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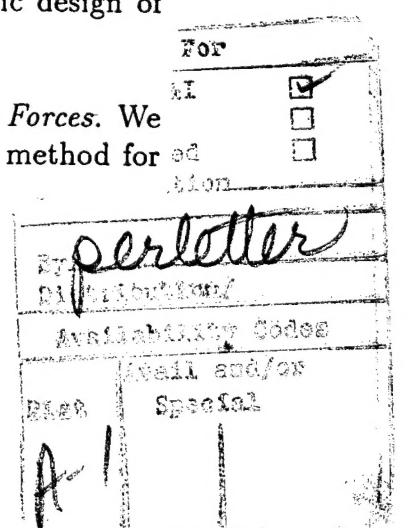
fixed offshore structures. This combines the narrow-band wave model (to estimate force statistics) with the separable cumulant model (to estimate corresponding response statistics). More recently we have begun to apply our dynamic response moment analysis to realistic, multi-degree-of-freedom (MDOF) ocean structures. Our current study focuses on a 37-node finite element structural model (111 translation/rotation degrees of freedom). Effects to be studied include the accuracy of the analysis technique, relative to more costly time-step simulation, as well as the effects of various modelling assumptions (e.g., different wave kinematics, structural properties that may cause resonances with wave force sub- or super-harmonics induced by nonlinearity, etc.).

Nonlinear Soils Effects on Flexible Ocean Structures. For flexible structures such as mobile offshore jack-up platforms, dynamic response can be significantly affected by nonlinear, hysteretic soil behavior. Simplified linear analyses cannot capture effects such as differential settlements under the legs of the structure. An ongoing practical question concerns whether a simple linear pinned foundation model is conservative, and if so to what extent. We find here that this degree of conservatism is seastate dependent: lesser conservatism at higher seastates and greater amounts at the low ones—suggesting that the benefit of foundation fixity might be significant only at low seastates.

Practical Dynamic Analysis of Large MDOF Structures under Nonlinear Random Wave Forces. Our recent research advances have provided analytical response moment estimates for large, linear multi-degree-of-freedom (MDOF) structures excited by nonlinear effects such as Morison drag, nonlinear wave kinematics, etc. In such cases, they hold the promise of reproducing results of time-step simulation studies of realistic structures (e.g., finite element models), providing response moments without the attendant statistical uncertainty of simulation and at a fraction of the cost.

Analysis of Combined Loads and Statistical Uncertainty. We have developed new models to include statistical uncertainty (due to lack of data) and model uncertainty (due to adoption of a limited, two parameter probability distribution model). These generalize any conventional distribution through a perturbation to match higher statistical moments. By preserving these moments, these models better match observed tail behavior. Also, model

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uncertainty is largely replaced by statistical uncertainty in these moments, which have been included in our analysis procedure. These models have been applied to model extreme combined load events, due to correlated wind, wave, and current. A presentation on this work was made at the 1990 Conference on Offshore Mechanics and Arctic Engineering; a paper is scheduled to appear in the Journal of Offshore Mechanics and Ocean Engineering, ASME.